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Current Harmonics Reduction using Hysteresis Current Controller (HCC) for a Wind Driven Self-Excited Induction Generator Drives

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Abstract

We report a hysteresis current controller which is used to reduce current harmonics in the wind powered SEIG system. The proposed wind energy conversion system can be modelled and the parameters are verified under the varying wind speed ranges. The overall efficiency of the system can be affected from non-linear inputs and the selection of controllers for harmonic reductions. The controller is used to control the hysteresis band in the current ripple and produced required output voltage. Hysteresis current controller is modelled and the current harmonic interruption is reduced for the wind energy system applications. The system components like Wind Driven SEIG, Rectifier and Hysteresis Current Controller are modeled using MATLAB/Simulink and the experimental results are verified.

Keywords: Hysteresis Current Controller, Self-Excited Induction Generator, Stand Alone Wind Power, Total Harmonic Distortions

1. Introduction

In renewable energy conversions the wind power energy conversion system is considered as one of the most active power generation systems. Higher orders of powers can be generated using wind turbines. The stand-alone wind powers generally apply to one application. Adequate power is required by AC drives in industries is very common. The voltage at constant frequency is produced by wind power turbines. The wind speed, directions, geographical locations are various inputs to the wind turbine. These are very much essential for power generation. The inputs to the wind turbines are not uniform and they tend to vary with respect to time. Various works on the terminal output of the wind turbine model is being executed. The terminal voltage and frequency are controlled by Direct Voltage Control (DVC)[1]. This direct voltage control is the most suited for voltage control applications with low harmonics. Pitch angle is used to track the variations in the wind directions. Variable Source Inverters (VSI)[2] are used to connect such type of turbine models. The proposed system is designed to get a very low current harmonics. In this proposed system self-excited induction generator is used as a wind turbine which is similar to induction machine which is driven by prime mover. The capacitors are connected in parallel to produce the voltage excitation. The capacitance is used for the excitation purpose so it is called as excitation capacitance[3]. In non-linear load applications hysteresis current controller is used to control the self-excited induction generators.

2. Modeling of Proposed System

The proposed system consists of a Self-Excited Induction Generator (SEIG)[4] is used as a wind turbine model. The hysteresis current controller is used to control the wind turbine output. Because of non-linear inputs the hysteresis current controller loop which is used to reduce current harmonics. The proposed system design is shown in the Figure 1.

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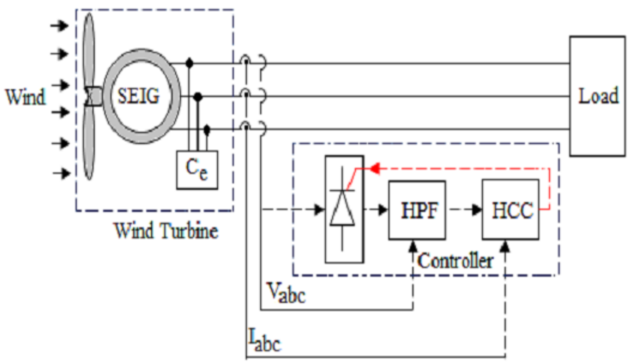

Figure 1. Proposed System model.

The wind turbine is used as a generator. Wind is used to drive the wind turbine when the blades are hit by the wind. For rotation the shaft of the generator rotor is connected to wind turbine blades. In wind energy system mechanical energy is translated into electrical energy. This energy transformation is used for the generation of power. The rotor speed is directly proportional to the output of the generator. In this proposed system self-excited induction generator is used as a wind turbine which is similar to induction machine which is driven by prime mover. Based on the voltage and current ratio the excitation capacitance value is decided. Moreover this excitation capacitance value should be constant during the power energy generation process. Synchronous speed test is conducted to determine the excitation capacitance. In the synchronous test, the no load saturation curve is obtained by running a machine at normal rated frequency in synchronous test. When the motor is driven using a prime mover or coupled to a DC motor which is driven at a speed corresponding to the synchronous speed of the machine at its rated frequency, the voltage will be developed at the stator terminal. The difference between the rotor and stator current is considered as a magnetizing current in which the slip value is zero practically. The critical capacitance range is obtained from the no load curve under linear region. From the curve the excitation capacitance is within the limit. The rated rotor current is used to determine the maximum capacitance. Once the capacitance value falls below the minimum value or if it exceeds the maximum values is not eligible for obtaining reduced power loss at the rated voltage. The critical capacitance value is obtained by this analysis which is used in excitation of the Self Excited Induction Generator system. The output voltage of the wind driven induction generator can be controlled and the DC ripple current is reduced by the series inductor filter[11]. The performance of SEIG connected with a three-phase diode rectifier feeding an R-L load is derived and the parameters can be evaluated[12].

3. Modelling of Hysteresis Current Controller (HCC)

The Self-Excited Induction Generator generates a various current waveforms based on wind turbine input parameters like wind speed and wind direction. If there exist any variations in wind speed and wind direction results in a distorted output current. There exists a ripple in the current content. The Figure 2 shows the proposed system using a Hysteresis Current Controller (HCC).

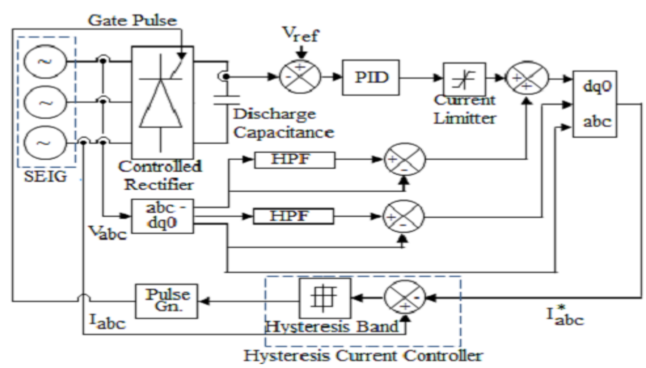

Figure 2. Modelling of proposed Hysteresis Current Controller loop.

Self-excited induction generator wind turbine is used to generate the input power. The output of the power generator is connected to a discharging capacitance through a three phase controlled rectifier circuit. A short circuit switch is used for charging and discharging of the capacitance. The desired output can be obtained by giving the comparative output error to PID controller. The voltage regulation in induction generator for non-linear loads can be satisfied using STATCOM based voltage regulator[5]. The current harmonics are reduced by using hysteresis current controller reduce the current harmonics so a comparative modelling of the input current and the current obtained from the current controller is done. The reference frame theory is used for this. The dq0 is converted in to abc reference frames by using reference frame theory. The input current of the generator is compared with the output current. A hysteresis band is set along the current wave. The band gap of the hysteresis band is adjusted in order to reduce the ripple in the current waveform. The gate pulse of the controlled rectifier is produced by this error and which is connected to the input line of the load. The Figure 3 shows the hysteresis band formation in the current waveform.

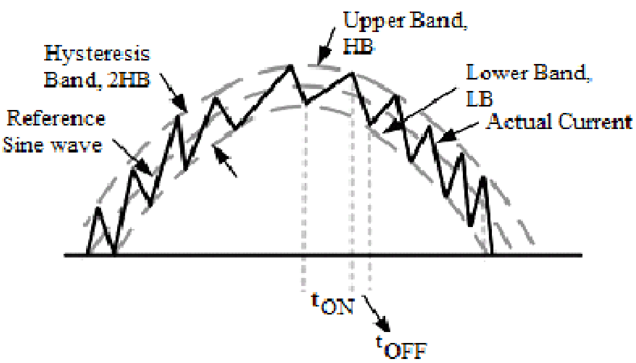

Figure 3. Hysteresis band formations.

The reference sine wave is expressed as,

$$I_{ref} = (V_{dc}/3V_p)^* I_{dc} \tag{1}$$

This equation can be adjusted for any variation in the load current. The neutral current i_{n1} in AC side $_{is}$ expressed as,

$$i_{n1} = \sqrt{2} I_{ref} \left[\sin\omega t + \sin\left(\omega t - \frac{2\pi}{3}\right) + \sin\left(\omega t + \frac{2\pi}{3}\right)\right] \tag{2}$$

Using the above expression, the injection current consists of the current through the three bidirectional switches and are given the equation,

$$i_{n2} = i_2 - i_1 = \frac{2I_{dc}}{3} \sin(3\omega t) \tag{3}$$

Where the current i_1 and i_2 are the currents. Using the above three equations, the current injection in order to minimize the harmonics.

4. Simulation Results and Discussion

Using MATLAB, the proposed circuit is modeled mathematically. The wind driven SEIG is modeled using the machine variable using the reference frame theory. The SEIG wind turbine is modeled for 4 kW output. The input parameters are varied like wind speed, pitch angles and the results are taken for those variations. The SEIG wind turbine generator is modeled as a real time model. The wind driven Self Excited Induction Generator system is simulated under variable wind velocity. This is done to validate the SEIG power output for the varying input conditions. The output is measured by varying the wind velocity from 3 m/s to 12 m/s. A graph is plotted between wind turbine rotor speed and output torque and it is shown in Figure 4. It is observed that at a wind velocity of 12 m/s the rated power of the generator is obtained.

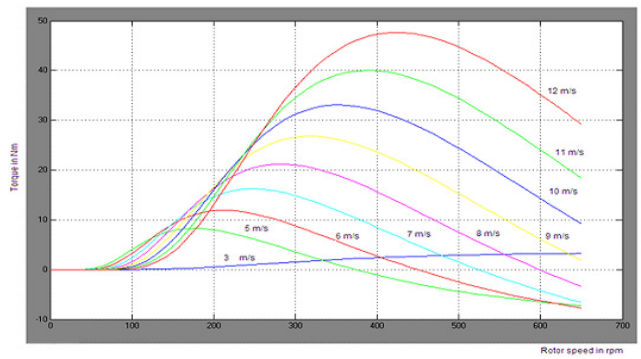

Figure 4. Simulation results of the wind turbine rotor speed Vs output torque.

The amount of power capable of being produced by a wind turbine is mainly depending upon the power co-efficient. The controlled output voltage of the induction generator is satisfying the electrical demand in single phase loads using a novel excitation scheme[6]. The torque developed by the wind turbine dependent on the wind velocity and rotor speed of the wind turbine. The cut in speed of the machine is 3 m/s. The rated torque produced by the wind turbine it is assumed that the wind speed is constant at 8 m/s. At higher wind speeds, the blades were feathered and the machine stopped. A 4kW power output is obtained by giving variable inputs. The wind driven self-excited induction generator output voltage and current is obtained with a wind velocity of 15 m/s and a pitch angle of 15^0. This output is shown in Figure 5.

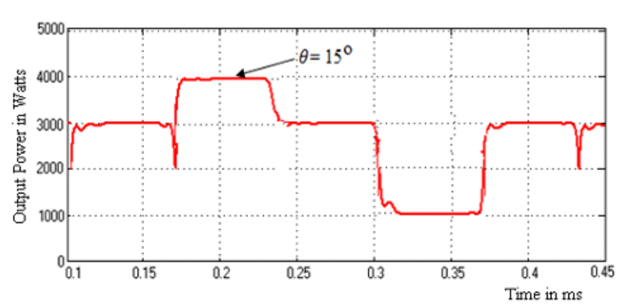

Figure 5. SEIG maximum power output when $\theta = 15°$.

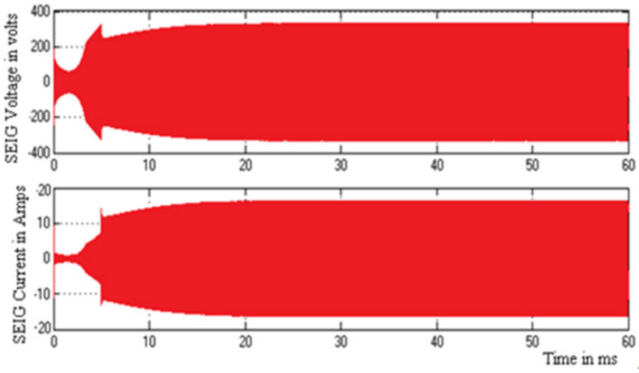

Figure 6. SEIG output voltage and current for v = 15m/s and $\theta = 15°$.

The SEIG voltage obtained is 415 volts and it is shown in Figure 6. The Phase voltages are V_a, V_b, V_c is shown in Figure 7.

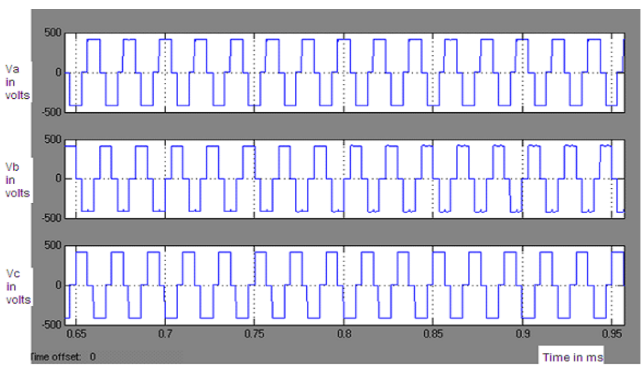

Figure 7. Simulation results of Line Voltage applied to the Load Terminals in volts.

At a constant wind velocity of 15 m/s, the wind driven SEIG is simulated and in order to obtain the maximum power, the pitch angle is varied. The harmonic interruption can be minimized using impedance source inverter in wind driven generator applications[7]. It should be noted that for a given wind velocity the maximum power is obtained from the wind turbine. The simulation can be done by synchronizing the variable turbine inputs like wind speed and the pitch angle and the self-excited induction generator wind power turbine is modeled. The selection of excitation capacitance for stand-alone three phase induction generator under varying wind velocity conditions can be focused[8]. The harmonic analysis of the Self Excited Induction Generator current without using the Hysteresis Current Controller is found to be the THDi and its value 20.27%. For varying wind velocity conditions, the power optimization is obtained in isolated self-excited induction generator using PWM inverter performance[9]. To obtain the efficient output, the current harmonics should be reduced. The total distorted current harmonic is shown in the Figure 8.

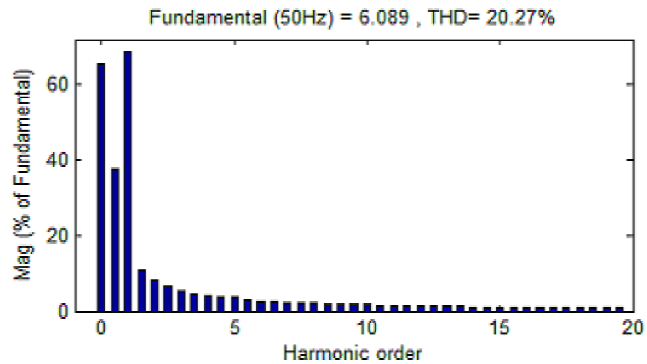

Figure 8. Total current harmonic distortion of SEIG wind turbine without the HCC.

In non-linear operations of self-excited induction generator wind turbine, the current harmonics are generated in the higher range. So the current harmonic levels should be reduced. In the proposed system, the current harmonics are reduced by using Hysteresis Current Controlled (HCC). The Harmonic reduction in efficient drive applications can be proposed using Hysteresis current controller and its output is obtained[10]. The RMS current of the self-excited induction generator wind turbine with and without using hysteresis current controller is shown in Figure 9.

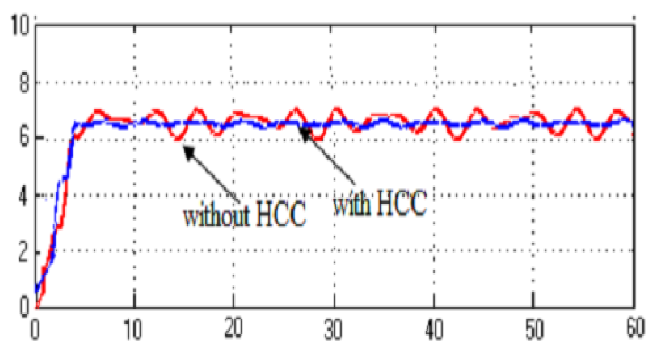

Figure 9. RMS Current of SEIG with and without HCC.

The RMS current of self-excited induction generator can be obtained after introducing the Hysteresis Current Controller and it is observed that harmonic levels are reduced very much. In self-excited induction generator the total current harmonics using hysteresis current controller is found to be 2.97%. The THDi obtained is shown in the Figure 10.

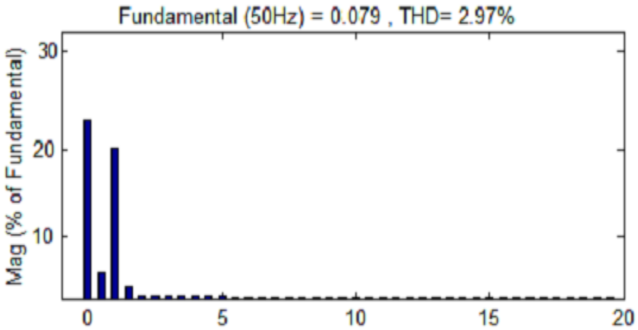

Figure 10. Total current harmonic distortion of SEIG wind turbine with HCC.

5. Experimental Model and Results

A same model is experimented by using a Self Excited Induction Generator which is driven by a DC motor as a prime mover. This system model is similar to a wind driven Self excited induction generator. A four pole, 415V, 7.5A squirrel cage induction generator is driven by a DC separately excited DC motor. The DC motor acts as a prime mover and drives the generator. The excitation capacitance value is taken as 60μF in the hardware setup. The armature rheostat of 220V/5A is used to control the speed of the DC motor. The hysteresis current controller is used to control the Self Excited Induction Generator driven by the prime mover is controlled. Figure 11 shows the experimental model of the proposed system.

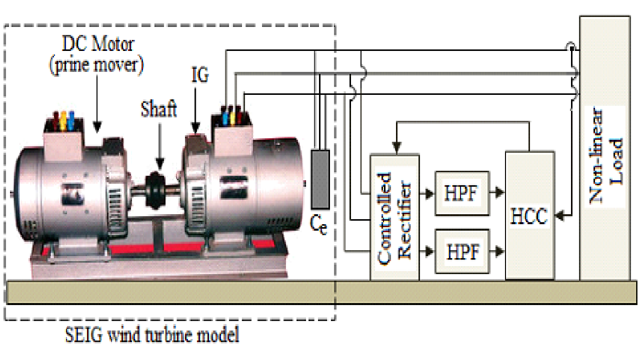

Figure 11. Experimental model of the proposed system.

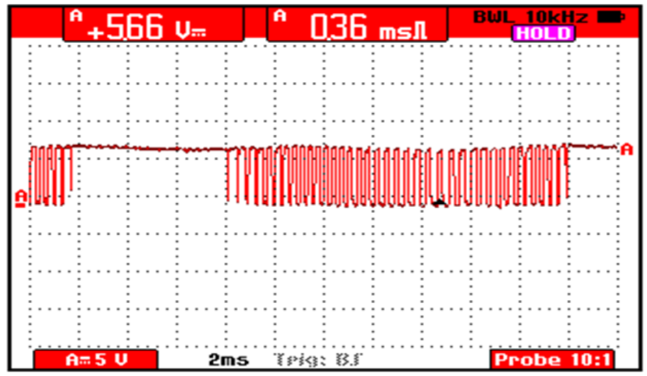

Figure 12. Gate pulse generated using Hysteresis Current Controller (HCC).

The Figure 12 shows hysteresis current controller generates the gate pulse. This gate pulse is applied to the controlled rectifier .The SEIG output is controlled and the current obtained has less harmonic levels. The Figure 13 shows the Self Excited Induction Generator output. The Figure 13(a) is the current waveform which is 7.5A and the Figure 13(b), is the total current harmonic distortion THD_i which is found to be 3.25%.

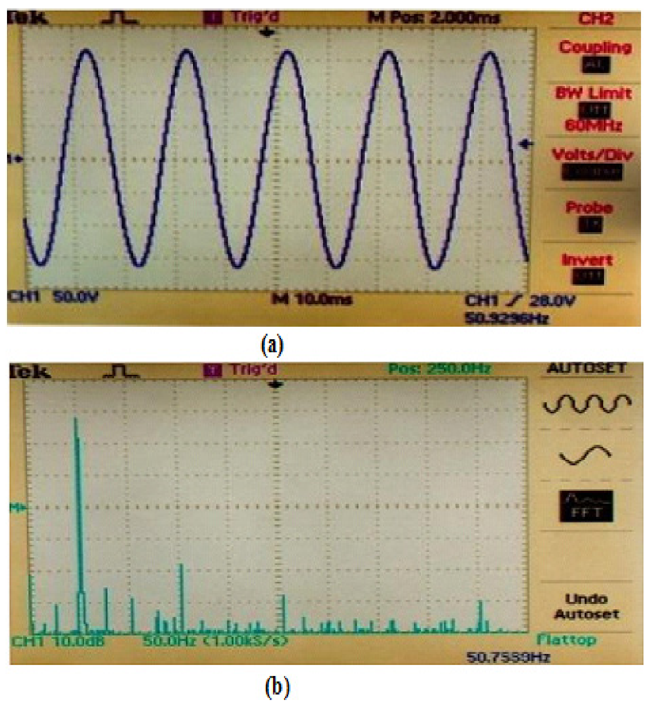

Figure 13. SEIG outputs. (**a**) Current 2.0 Amp/div. (**b**) THDi = 3.25%.

6. Conclusion

Self-excited induction generator was driven by wind in a nonlinear system introduces a current harmonics at a higher levels. The gear box setup can be used to make the wind turbine output as a constant from a variable input. More over there exist a large amount of power loss because of energy transfer and this will be a more expensive one. For any applications the current harmonics should be less than the standard value. The proposed system is designed for non-linear operations of self-excited induction generator applications a hysteresis current controller. In self-excited induction generator using hysteresis current controller reduces the current harmonics by nearly 20% when compared with the system without using a hysteresis current controller. Thus for a non-linear loads the power factor and the overall efficiency of the system is increased.

7. References

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